

## ***Interactive comment on “Mapping snow depth in alpine terrain with unmanned aerial systems (UAS): potential and limitations” by Y. Bühler et al.***

### **Anonymous Referee #3**

Received and published: 30 March 2016

The paper “Mapping snow depth in alpine terrain with unmanned aerial systems (UAS): potential and limitations” by Y. Bühler et al evaluates the ability and accuracy of UASs to estimate snow depth in alpine terrain. This is part of a small, but rapidly growing body, of literature that has begun to test the ability of small UASs to estimate snow depth at high spatial resolutions. This paper contributes a unique perspective by considering the accuracy of a multirotor platform in an alpine setting. The methods employed are solid and the results presented show great promise (RMSE <15 cm over grass surfaces and <30 cm over taller vegetation) as an alternative to laser scanning (airborne or terrestrial) in non-vegetated areas. I would recommend publication of these results in The Cryosphere but the manuscript does overstate the significance of this technique and the implications from this study.

I broadly agree with the comments of the other two reviews by M Nolan and A Prokop.

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The evaluation of the method to estimate snow depth is solid but the wrapping text needs work. The authors are proponent of using a multirotor for this work and I do not see why this bias is so strong without a direct comparison with a fixed wing platform. The authors clearly pushed their system beyond the manufacturer recommendations (Table 1 max wind speed 12- 15 ms<sup>-1</sup> yet they report good results in wind speeds of 20 ms<sup>-1</sup>) so just comparing manufacturer specs is an insufficient test. It would be sufficient for publication to present the results achieve with this specific platform without overstepping and making broad comments on multirotor vs. fixed wing platforms.

The writing could use some work. Many sentences are awkward or unclear to me and need rewriting (see the specific comments for a non-exhaustive list). There is inconsistent writing tense that, once corrected, will make the manuscript easier to read.

Specific Comments:

Title: while potential and limitations are in the discussion the majority of the paper deals with producing and assessing the accuracy of the snow depth maps. Perhaps the “potential and limitations” could be dropped to simplify the title

Page 2 Line 1: “spatiotemporal distribution, and variability of snow depth (HS” -> “spatiotemporal snow depth (HS) distribution” . . . may be more clear

Page 2 Line 10: The Nolan review does bring up a fair point regarding making statements/ comparing the economics of this system to manned platforms (or even other UASs). Without doing a full economic analysis these statements are merely speculative. As well, regulations affecting UAS (which are rapidly changing and vary by nation) and aircraft operations s may play a larger role in determining the application of this method than simply comparing the ticket price of equipment. With all of these competing factors, which are beyond the scope of this paper or journal, perhaps it may be more appropriate and straightforward to limit this paper an assessment of the capabilities of the method.

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Page 2 Line 13: “ an unmanned aerial system (UAS)” as you only used one platform- this was not an intercomparison.

Page 2 Line 19-20: “monitor the ablation”-> “monitor the snow ablation”. What about at the second site? I would recommend you mention snow depth was estimated once here to keep the text balanced.

Page 2 Line 23-24 and throughout text: “better than” -> “less than”

Page 2 Line 24-26: awkward ending to this sentence. Please rewrite.

Page 3 Paragraph 1: This paragraph is a list separated by semicolons without any sort of closing to wrap up these points. Rewrite without using semicolons as it is rather awkward.

Page 3 Line 13: Remote sensing is a field of study with many different tools not a tool itself like UAV SfM. Rewrite.

Page 3 Line 15- 17: perhaps put your definitions of snow depth into a methods section.

Page 3 Line 21-23: Unnecessary sentence.

Page 3 paragraph 2 and 3: After suggested edits merge these two paragraphs.

Page 4 Line 5-6: “were not feasible to most applications” –awkward

Page 4 Line 11: “Throughout the last years,” -> “Recently,”

Page 4 Line 11-16: replace semicolons with commas.

Page 4 Line 20. Replace colon with period.

Page 4 Line 20-21: As you are likely already aware de Michele 2015 in TCD is now de Michele 2016 in TC. Other recent examples can also be found in TCD (Harder et al., 2016 and Marti et al., 2016)

Page 4 Line 23-27: rewrite to avoid faulty parallelism. “implementing sensors capable

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of measuring at e.g. near infrared wavelengths” is unclear

Page 5: Why are sections 2.1 and 2.2 distinct from each other?

Page 5 Line 10: can you define “high positional accuracy”. How accurate is the positioning? Is this standard GPS accuracy ie +/- 5m?

Page 5 Line 17-19: Can you be more explicit on the color bands with and without filters? A table would be valuable to quickly compare the EM spectrum being sampled in the various configurations.

Page 6 Line 1-20: perhaps a new section along the lines of “UAS deployment”

Page 6 Line 11:” important key” redundant. Pick one

Page 6 Line 12: delete “feasible”. Redundant

Page 6 Line 13-15: the capabilities of camera by themselves do not enable generation of highly accurate DSMs. Other factors such as overlap are critical. Rewrite to clarify what you are trying to say.

Page 6 Line 19: not simply limited by weight. Also limited by space and power. In case of Ebee specifically, cameras are primarily limited by what the manufacturer offers as only Sensefly sensors can be used in the ebee.

Page 6 Line 19-22: I disagree with this simplification. The octocopter may be easily transportable but with an effective flight time of <10 minutes the operator needs to be in or directly adjacent to the area of interest. While a larger system may not be able to be transported as near to the area of interest as a multicopter it can travel further to overcome such a disadvantage. It may necessary to emphasize that the best platform for the job will be site specific.

Page 6 Line 23: Speculation. Will be site specific.

Page 6 Line 9-11: Tense is inconsistent

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Page 6 Line 13-20: What parameters were used in this study? Was the accuracy of the estimated snow depths sensitive to these parameters? Was this tested?

Page 6: Point cloud generation is discussed but how are the DSMs and orthomosaics generated. This needs to be added.

Page 6 line 23 and elsewhere: change “well-accessible” to “easily accessible” or something less awkward.

Page 7 line 5: delete “quite”

Page 7 line 9: “usually not exposed” -> “not usually exposed”

Page 7 Line 9-11: how were slope angles estimated? From the DSM?

Page 7 Line 13-15: How was this overlap determined to be optimal? Was this determined through trial and error? Was this a recommendation? How do you determine DSM quality? Did you test quality versus time? Justify the selection of this overlap more clearly.

Page 7 Line 18-20: Were multiple batteries switched out during each image acquisition period or was acquisition limited to what could be acquired off a single battery. Switching out batteries greatly extends the duration of any proposed missions and this information will help potential users evaluate your experience.

Sect. 3.1 and 3.2: please include the size of the areas mapped at each site.

Page 9 Line 17: Why was NIR selected at this site and not at Tschuggen? Does this change the accuracy results? Was there a test of the different wavelengths at a common site and time to see if this would influence the accuracy results?

Page 10 Line 3: delete “e.g.”

Page 10 Line 5: spelling “referene”

Page 10 Line 6: “are resulting” -> “results”

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Page 11 Line 4: Do you have confidence that you were actually able estimate a mean snow depth of 1cm? Granted that this is an areal average of variable snow depth but this is a lot less than any of your estimated geolocation or snow depth errors.

Page 11 Line 18: “is an average systematic underestimation of HS by 0.2 m” is this the same as bias? Perhaps it would be good to use terms common to other papers on this topic (ie Harder et al 2016)

Page 11 Line 26-29: Are these values an average of the errors for all respective snow depth in each class for all flights? This is unclear. What is mean shift? Same as bias? Clarify/keep your terminology consistent.

Page 12 Line 3: “RMSE of  $\sigma$  is 0.04 m” based on all flights? Clarify please.

Page 12 Line 13: Would it be possible to add a legend/color bar to the animation to more easily interpret the snow depths.

Page 12 Line 28: I fail to see the value of including the correlation coefficient. The RMSE is sufficient while the R2 (due to the small RMSE and large range in snow depths) will give a deceptively good value.

Page 13 Line 1: can make text more concise if you refer to this as bias (if that is what it is).

Page 13 Line 3-4: This sentence is unclear to me as to what you are comparing.

Page 13 Line 20-21: delete “which is the appropriate starting/landing procedure we apply in alpine terrain”. Redundant.

Page 13 Line 21-23: Perhaps. But this is platform and site specific so such a strong universal statement is rather speculative.

Page 13 Line 23-24: Did you actually fly in -30C or is this also speculative?

Page 14 Line 6-9: Without an actual comparison this is also speculation. Flying con-

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ditions will be site specific and fixed wing platforms have vastly different capabilities negating any universal conclusions.

Page 14 Line 13: delete "However,".

Page 14 Line 18: DSM instead of "DEM"?

Page 14 Line 23: delete "However,".

Page 15 Line 6-12: You used NIR and no-NIR imagery in this study already. Can you make any comments on this topic already?

Section 5.3: Coregistration is important but this section could be removed as the different methods were not compared as far as I can see and doesn't directly contribute to the results of the paper.

Page 17 Line 13: add recent papers as previously mentioned.

Page 17 Line 15-16: Maximum altitudes of UAV's is generally quite low due to regulations (which will of course vary by country) so this is likely unfeasible.

Page 18 Line 9-26: I agree with the M Nolan review that this should be moved to the discussion.

Page 19 Line 1-3: Rewrite final sentence as it is unclear.

Figure 5: in caption, do the R2 values refer to HS measurements? Clarify. Remove shading from points on plots

Figure 7: If you do keep this section (re: Prokop review) clarify what the bars and line represent (unclear which is mean snow depth and which is standard deviation). Also make bars a solid color.

Figure 8: what is the line in the HS measurement plot below the 1:1 line? Remove or explain.

Rearrange order of figures to reflect the order they are referred to in the text.

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Any mention of "significance" should be removed unless backed up with statistical tests.

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Interactive comment on The Cryosphere Discuss., doi:10.5194/tc-2015-220, 2016.